Spatial Visualization Skills Training at Texas State University to Enhance STEM Students Academic Success

Dr. Clara Novoa, Texas State University

Dr. Clara Novoa is an Associate Professor at the Ingram School of Engineering at Texas State University. She has a Ph.D. in Industrial Engineering and her research areas are Dynamic and Stochastic Programming and Parallel Computing to solve mathematical optimization problems applied to logistics and supply chain. Dr. Novoa has 19 years of experience in academia and 4 years of experience in industry. Dr. Novoa is receiving funding from NSF through Texas State STEM Rising Stars (2015-2019) and ME-Green: Manufacturing for the Environment by Generating Renewable Energy in Enterprise Networks (2017-2020). Texas State STEM Rising Stars is a four-years grant related to increase the first and second year retention and graduation rates of students in STEM. ME- Green is a three-years grant to model and design a grid-connected onsite generation system featuring renewable power to realize zero-carbon industrial operations. Dr. Novoa has been also committed to research on strategies to achieve gender equity and cultural inclusiveness in science and engineering.

Dr. Bobbi J. Spencer, Texas State University

B.J. Spencer, Ph.D., AIA

Dr. Spencer is an Assistant Professor of Practice in the Department of Construction Science and Management at Texas State University where she focuses on the architectural courses, VDC, and is the internship coordinator. In 2017, she obtained her Ph.D. in Education from Texas State University with the emphasis on professional education. A registered Architect in the State of Texas, she received a Master of Architecture from Texas A&M University in 2007 where she participated in a study abroad semester at the Universita della Svizzera italiana, Accademia di Architettura di Mendrisio, Switzerland following 23 years of industrial experience in architecture and construction.

Dr. Spencer's research interests include: Professional & International Education: architecture and construction Experiential Education: study abroad, internships Virtual Design, Construction and Operations (VDCO) Education in online and virtual environments

Ms. Leona Hazlewood, Texas State University

Hailing from Texas as of three generations deep, Ms. Hazlewood understands the worth of hard work, fresh water and education. With a bachelor's degree in marine biology from Texas State University (1999), Ms. Hazlewood learned a sincere appreciation for our ecosystems and sustainability. Upon graduation, gainful employment proceeded in The Xiphophorus Genetic Stock Center which bestowed a sincere interest in research to help solve our world's problems, including cancer research, preservation of aquatic species, and genetic analysis. This inspiration led Ms. Hazlewood to an academic advisor position, thus allowing her to complete a master's degree in chemistry (2013). The opportunity of higher education has led Ms. Hazlewood to a path of educating our future generations through experiences and shared learning as a US 1100 – freshman seminar instructor since 2014 and as an academic advisor for science and engineering since 2008.

Dr. Araceli Martinez Ortiz, Texas State University

Araceli Martinez Ortiz, PhD., is Research Associate Professor of Engineering Education in the College of Education at Texas State University. She leads a comprehensive research agenda related to issues of curriculum and instruction in engineering education, motivation and preparation of under served populations of students and teachers and in assessing the impact of operationalizing culturally responsive teaching in the STEM classroom. As executive director of the LBJ Institute for STEM Education and Research, she collaborates on various state and national STEM education programs and is PI on major grant initiatives through NASA MUREP and NSF Improving Undergraduate STEM Education and NSF DUE . Araceli holds Engineering degrees from The University of Michigan and Kettering University. She holds a Masters degree in Education from Michigan State and a PhD in Engineering Education from Tufts University.

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Abstract

A diagnostic of thirty questions administered to incoming STEM students in Fall 2013 and Fall 2015 - Fall 2018 reflects that their spatial visualization skills (SVS) need to be improved. Previous studies in the SVS subject [1], [2], [3] report that well-developed SVS skills lead to students' success in Engineering and Technology, Computer Science, Chemistry, Computer Aided Design and Mathematics. Authors [4], [5] mention that aptitude in spatial skills is gradually becoming a standard assessment of an individual's likelihood to succeed as an engineer.

This research reports the qualitative and quantitative results of a project designed to improve SVS's for STEM students managed under two strategies. The first strategy utilized was a series of face-to-face (FtF), two-hour training sessions taught over six weeks to all majors in STEM. This strategy was offered in Spring 2014 and every semester from Fall 2015 - Spring 2018. The second strategy was an embedded training (ET) implemented by one faculty from Fall 2017- Fall 2018. The faculty embedded the training in the US 1100 freshman seminar and was highly motivated to increase awareness of students on the importance and applicability of SVS in their fields of study. As reported by Swail et al. [6], cognitive, social, and institutional factors are key elements to best support students' persistence and achievement. Both interventions used in this project encompassed all these factors and were supported by an NSF IUSE grant (2015-2019) to improve STEM retention.

The FtF training was taken by 34 students majoring in diverse STEM fields. Its effectiveness was statistically assessed through a t-test to compare the results in the Purdue Spatial Visualization Skills Test - Rotations before and after the training and through analysis of surveys. Results were very positive; 85.29% of the participants improved their scores. The average change in scores was 5.29 (from 16.85 to 22.15; 17.65% improvement) and it was statistically significant (p-value 3.9E-8). On the surveys, 90% of students answered that they were satisfied with the training. Several students reported that they appreciated a connection between SVS, Calculus II and Engineering Graphics classes while others based the satisfaction on perceiving the critical role SVS will play in their careers.

Results from the ET strategy were also encouraging. Teaching methods, curriculum and results are discussed in this paper. Adjustments to the teaching methods were done over 3 semesters. In the last semester, the faculty found that covering the modules at a slower pace than in the FtF training, asking the students to complete the pre-and post-diagnostic in class, and introducing the Spatial VisTM app to provide students with additional practice were key elements to assure students success and satisfaction. In conclusion, both strategies were demonstrated to be powerful interventions to increase students' success because they not only offer students, particularly freshman, a way to refine SVS but also increase motivation in STEM while creating a community among students and faculty. The ET is effective and apt to be institutionalized. Lastly, this experimental research strengthens the literature on SVS.

Introduction

In an effort to increase both enrollment and retention of STEM students at Texas State University, a multi-disciplinary research group of faculty in the College of Science and Engineering formed to identify effective interventions. In Spring 2015, the group was awarded a four-year grant from the NSF - IUSE program with the specific goal of improving freshman and sophomore retention rates in *Chemistry, Computer Science, Engineering, Engineering Technology, Mathematics and Physics* and increasing the number of female, Hispanic and African American students completing undergraduate degrees in these STEM fields.

To support the goal of the NSF-IUSE grant, the authors had the idea of running an entirely new research project at the institution between Fall'15 - Fall'18 and formed a committee to run the project with the help of some faculty in the funded NSF-IUSE group. The project consisted of assessing and improving SVS skills of students, especially freshman, in the College of Science and Engineering with the goals of improving student retention, creating community between faculty and students and increasing students' confidence for success in their chosen majors. This decision was also a result of the authors' interest on SVS literature and the successful experience of offering a pilot face-to-face (FTF) training on campus to improve SVS for 6 talented, low-income students in an NSF S-STEM scholarship program in Spring '14. Previous studies in the SVS subject [1], [2], [3] report that well-developed SVS lead to students' success in Engineering and Technology, Computer Science, Chemistry, Computer Aided Design and Mathematics. Bairaktarova et al. [4] mention that aptitude in spatial skills is gradually becoming a standard assessment of an individual's likelihood to succeed as an engineer.

Support from industry provided the funds needed to acquire training materials created by Sorby [5] leaving the authors the challenge of identifying the appropriate strategy and delivery format to get an acceptable number of student participants and relevant data for this research. The first strategy utilized was a series of FtF, two-hour training sessions taught over six weeks to all majors in STEM. The results reported for this first strategy consolidate the ones obtained in the pilot training offered in Spring'14 and in the FtF training offered in the period of Fall'15-Fall'18. The second strategy was an embedded training (ET) mainly implemented by one faculty from Fall 2017- Fall 2018. The faculty embedded the training in the US 1100 freshman seminar and was highly motivated to increase awareness of students on the importance and applicability of SVS in their fields of study. As reported by Swail et al. [6], cognitive, social, and institutional factors are key elements to best support students' persistence and achievement.

The contribution of this research is to provide qualitative and quantitative results of a project designed to improve SVS's for STEM students in a minority serving institution to facilitate other universities in and outside the U.S. to start a similar project using the lessons learned in this one. The paper consists of 4 sections. The first one presents the literature review. The second one reports on the delivery format and lessons learned for the FtF and ET strategies researched. Section three summarizes the results of these two strategies. Section four provides conclusions and future directions.

1. Literature Review

Spatial visualization skills (SVS) enable a person to mentally project between both 2D and 3D objects, thus, increasing their ability to understand the object's spatial context. For the STEM disciplines, this deeper understanding has been proven to be a learnable skill that enhances a student's abilities to visualize complex objects across the STEM-class spectrum; inspiring great interest in the discussions on student retention [1], [7]-[13]. The work of Dr. Sheryl Sorby at Michigan Technological University has connected lacking SVS to different demographics, such as gender, with her research acting as a springboard for future studies on other demographics. One of those is on international students in STEM disciplines with the research on the impact of SVS training given the retention being of vital importance to STEM academic programs [14], [15].

Identifying the best strategy for an SVS intervention is one of the first steps in implementing the training. Per Metz, et al. [3] research, they organized a cohort of schools that followed the ENGAGE Strategy Implementation Workshop's example and utilized their resources and assistance. Each ENGAGE school implemented the strategies and shared the steps and results they had. Inspired by this and other research, a workbook, CD, software, video, and app for tablets have become available for different learning styles [5]. Encouraged by these previous research experiences, Texas State University implemented some of these approaches. The way in which they were implemented is discussed in the next section.

2. SVS Training Strategies Researched

2.1 Face-to-Face (FtF) Training

The face-to-face (FtF) training was created to offer freshmen STEM students the opportunity to build their SVS. This training was advertised at first through flyers, such as the one depicted in Appendix A, and email invitations en masse to STEM students. They were invited to take an initial SVS assessment electronically, through the learning management system (LMS) available on campus. Those students with low scores on the assessment were encouraged to attend the training we coined "Viz Stars". The training also welcomed students with good scores and interest on improving them and some non-freshman students reached by faculty in the NSF - IUSE grant. The initial assessment used was the Purdue Spatial Visualization Skills Test - Rotations (PSVT-R) [16], [17]. Some authors have contrasted the electronic and paper formats for administering this assessment. In [18] authors found that freshmen taking the test through an LMS scored on average a full point lower than those taking a paper version of the test, even though the LMS group had higher Math ACT averages than the paper groups. They also mentioned that some students may score lower because in the electronic version it is not possible to make marks. While in the paper version, even if students are told not to make marks several students do. However, the electronic test easily displays immediate results to the student and is very convenient for faculty if large amounts of students are taking the test.

Viz Stars met for six Fridays for a 30-minute lunch with food, community building, and the opportunity to listen a faculty or industry speaker sharing interesting STEM topics. The students then adjourned to a computer lab where the two-hour Viz Stars curriculum was presented. From the gracious gift from a leading industry supporter, one of the authors, who was the class instructor, provided the students with a free copy of the workbook, "Developing Spatial Thinking" by Sheryl Sorby [5] and access to the software that paralleled the workbook.

A lesson learned is that students enjoyed working through the different chapters digitally, especially because they voluntarily joined the course. While in the training, they also had the opportunity to ask questions and create a community with other peers and faculty. This further motivated them to practice outside of class. Informed consent forms were collected on day one and, after the students completed their final assessment and exit survey, a gift card and t-shirt were issued to those with no more than two absences at the end of the course. The final assessment was the PSVT-R [7] also. In Fall 2016, the authors invested in the videos created by Sorby [5] which discussed the workbook chapter's content. The videos were presented at the beginning of each chapter and the authors learned from the students that this material facilitated the understanding of the modules to some extent. Due to the videos being designed to be used with the workbook chapters, the video content proved to be a concise and cohesive introduction to the chapters.

As our volunteer enrollment from Fall 2015 and Spring 2016 only yielded ten students that were interested in improving their spatial visualization skills, the committee discussed alternatives for marketing the course more effectively. While still offering the option of direct enrollment for students, the committee implemented reaching out to other faculty in the STEM disciplines and asking for their support in advertising the training and recommending students in their courses to participate. Some of the faculty contacted had attended a summer faculty seminar where the relevance of SVS and its connection to STEM courses was explained by two of the authors. In this summer seminar, faculty had expressed interest in advertising the course and/or going over the course materials. An additional alternative offered to faculty was to embed the Viz Stars training into their own courses using the workbooks, software, and videos the group had available and giving them a monetary incentive to compensate them for some extra work that they would incur. Faculties that wanted to assess their SVS, take ideas for how to motivate students towards improving SVS and run such embedded training (ET) were also welcomed to enroll in the Viz Stars FtF training.

2.2 Embedded Training (ET)

Starting in Spring 2017, one of the authors started to offer a pilot embedded training (ET) session to an architectural class already containing some of the components of the SVS training. The workbook was assigned as homework. Due to the nature of the class, with its already existing 36+ assignments, the amount of homework the ET contributed was frowned upon by the students and the author did not elect to continue. Another faculty in the same department embedded the training in another course during the same term, but also had similar results.

The authors did not give up on researching which course would be suitable to have a successful ET session and what would be the recommended format. In Fall'17, one faculty in the Chemistry department and another author of this paper were each willing to embed the training in their Organic Chemistry II honors and US 1100 freshman seminar courses, respectively. The faculty in the US 1100 course offered the training as a graded project while the other faculty gave it as an extra credit. Both experiences were to some extent successful on engaging students and on helping them to improve their SVS. The remainder of this section reports on the experience of embedding the spatial visualization training in the US 1100 course, because this one was the one that used the most diverse set of teaching strategies available and had the highest number of students enrolled.

The SVS training was embedded in four sections of US 1100 taught over the course of three semesters (two sections in Fall'17, one section in Spring'18, and one section in Fall'18). This allowed data to be captured from a total of 44 students. Throughout the semesters, several pedagogic techniques [19] were utilized to help improve students' participation and performance in the training. These techniques included: (1) a free computer application to allow for increased practice and visual representation of concepts, (2) in class completion of assessments, (3) weekly monitoring of module progress, and (4) incentivized grading for the completion of the training.

Freshman seminar (US 1100) is a course on the introduction to college life. It is a 15-week course that meets for 50 minutes per week and is required for all new, incoming freshmen to Texas State University. The flexibility in curriculum for this class allows for an ideal venue to present the SVS training in a student's first semester of college if no other options to present this material are readily available.

At the beginning of each semester, the students were provided a syllabus detailing the ET semester events. The syllabus for the Fall'18 section is presented in Appendix B. The initial introduction, benefits, and applications of visual and spatial acuity were emphasized to help bring relevance to the ET program. The initial PSVT-R pre-assessment was administered during the 50-minute class and a timeline was established for the completion of the individual modules, post-assessment, and exit survey. Access to the computer preparation modules, accompanying videos, and the supportive computer application were also detailed in the initial introduction to the ET. A lesson learned is that providing students with an introduction and background, a syllabus for the training and the opportunity to complete the pre-quiz (i.e. diagnostic) in class proved to help to provide meaning and relevance to the program. At the end of the semester, class time was given in class to complete the PSVT-R post assessment and the exit survey. A second lesson learned is that by allowing the time in class for students to complete the post assessment and exit surveys, participation was ensured, and a more robust set of data was available for review. For instance, by taking the assessments in class, it encouraged the students to effectively use the time allowed for the test instead of answering the questions in a rush.

Furthermore, introducing the training early in the semester and having consistent reminders and progress monitoring throughout its duration helped students not be overwhelmed with the curriculum and set a steady pace during the entire semester. If the training is implemented early, it allows 10 weeks total so the students can work on one module per week. In this experience, workbooks with practice problems were collected each week in class and reviewed for progress. This progress was monitored and recorded each week in a simple Excel spreadsheet documenting completion. The authors learned that incentivizing students by providing a final grade that evaluated their participation in the full training program is also necessary to maintain interest and motivation in the program. This lesson learned agrees with the literature in [19], [20].

The supportive computer application that the author used in the ET is the Spatial VisTM Engineering app offered by EGrove Education, Inc. [21]. It assisted students with extra interactive practice and was viewed generally as supportive yet limited by the students. This computer application was used in addition to the video modules, workbook, and computer program administered with the FtF Viz Stars training and created by Sorby [5].

3. Results

3.1 Face-to-Face (FtF) training

An analysis of the database of 502 students participating in the Viz Stars PSVT-R diagnostic shows that SVS training is needed for STEM students at Texas State University, particularly for females. These results are presented in Figure 1. The percentage of male passing was 53% (167 out of 313) while the percentage of female passing was 34% (55 out of 161). The percentage of students who did not report gender had a passing rate of 43% (12 out of 28). The overall percentage of students passing the test was 47% (i.e. 234 out of 502). The diagnostic has 30 questions and a passing score was 21 or more correct answers (i.e. 70%). A t-test showed that there is a significant difference between the scores of male and female (two populations t-test p-value 0.00028).

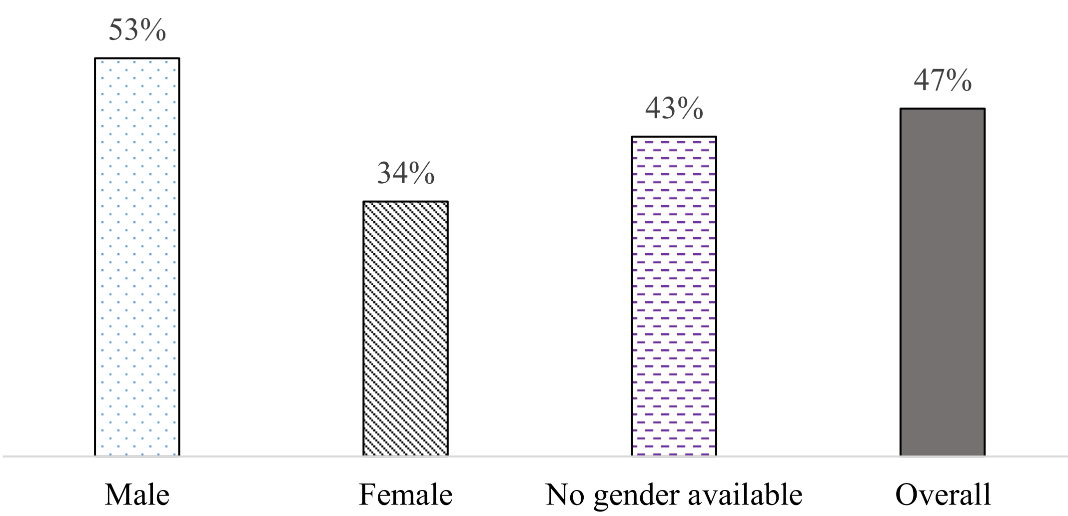


Figure 1: Percentage of the students scoring above 70%

Table 1 and Figure 2 present the differences found in the percentage of students passing the diagnostic by ethnicity. Asian and White students have the largest percentages. Because the Black and Hawaiian categories have a very low total number of students, no separate analysis is done for these categories. However, if merging Black and Hawaiian with the Hispanic category, the percentage of passing students is 39% and it is lower than the above 55% gotten for the Asian and White categories. Statistics in Figure 1 and 2 and Table 1 motivated the authors for especially targeting female, Hispanic, Black and other minority students in the SVS training while also allowing the inclusion of White, Asian and other ethnicities.

Table 1: Percentage of students passing the PSVT-R diagnostic by ethnicity

Category	%	No. of students passing	Total students
White	56	72	128
Black	15	4	26
Hispanic	45	50	111
Asian	61	14	23
Hawaiian	25	1	4
Other	54	7	13
Unknown ethnicity	44	86	197
Overall	47	234	502

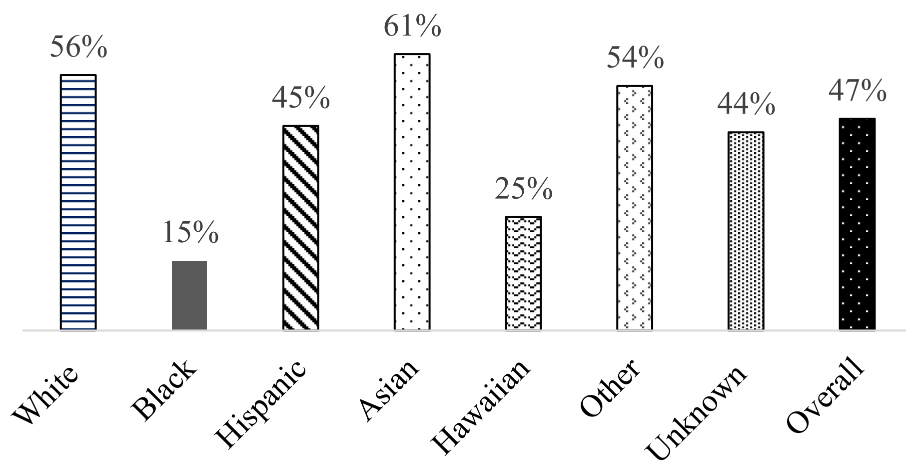


Figure 2: Percentage of the students scoring above 70% by ethnicity

The size of the database of scores for students enrolling in the Viz Stars FtF training strategy is smaller than the one for students taking the PSVT-R diagnostic. It consists of exactly 34 students, 13 (38%) male and 21 (62%) female all majoring in STEM fields. The demographics of the participants are 11(32%) White, 18 (53%) Hispanic, 1 (3%) Black, 2 (6%) Asian and 2 (6%) other. Analysis of this database shows that the FtF training has been effective to improve SVS in the participants. Twenty nine out of thirty-four students (85.29%) strictly improved their scores after taking the training. Average improvement was 5.29 points (17.65%). This average improvement is statistically and practically significant. The paired t-test p-value is 3.9E-8 while the average scores went from a non-passing score of 16.85/30 (56.2%) to a passing score of 22.15/30 (73.8%).

The tool for collecting qualitative data was exit surveys. Analysis of them reflects that the FtF training satisfied students' expectations according to 90% exit survey responses. In 74% of the responses, those expectations were explicitly reported as to improve SVS and utilize the skills to increase performance in STEM courses. Thus, there is a very good agreement between the qualitative results from the surveys and the quantitative results reported in the previous paragraph. Also, the authors of this paper feel grateful, because they were able to transfer to the students not only the SVS skills, but also a sense of confidence in their ability to succeed in STEM fields.

3.2 Embedded Training (ET)

An analysis of the entire database of 44 students (about 80% female and 20% male) participating in the ET in the US 1100 course shows that 22 students were able to improve or keep the same scores. It corresponds to 50% of the students taking the ET. The average improvement for those 22 students was 3.68 points. Figure 3 shows how the percentage of students passing the test after the training improved over the semesters researched reaching 64% in Fall'18. The authors know the Fall'18 semester was the one in which all the strategies described in Section 2.2 were entirely in place. Thus, the authors believe that percentages of passing rates such as this or higher can be achieved once an instructor has taught the training over several semesters, implemented the pedagogical tools mentioned in Section 2.2 and attended comments from the exit surveys.

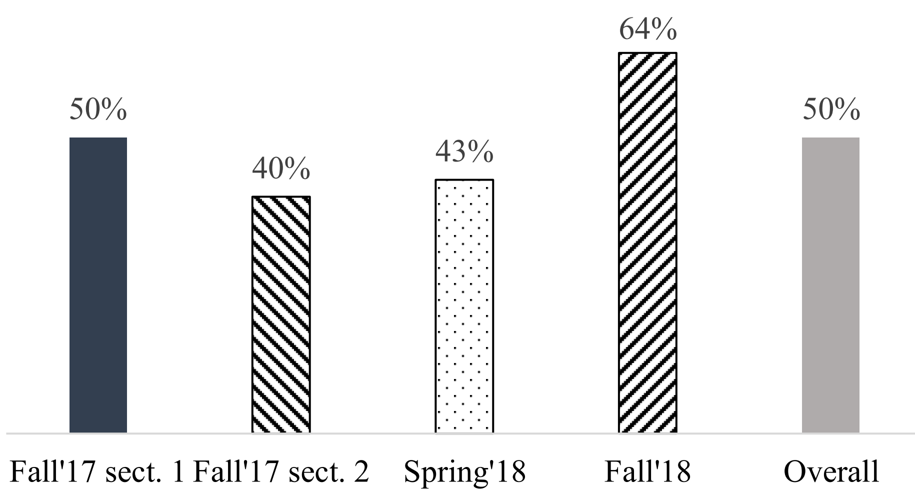


Figure 3: Percentage of students passing the ET in the US 1000 course

However, no statistical evidence was found to conclude that there is a significant difference between the scores in the pre and post PSVT-R diagnostic of the 44 students participating in the ET. Average scores for both the pre and post diagnostic remained close to 14. Even if 50% of students improving SVS is an encouraging percentage, the remaining percentage of students had decreased their scores. A factor that may have contributed to such results is that the sections had STEM (about 40%) and non-declared and non-STEM majors in them (about 60%). The authors did not want to analyze the two groups separately due to the small size of the resulting data sets.

Besides, there is no previous study related to SVS of STEM and non-STEM majors in our campus; such a study could be of interest in the future when the database becomes more robust.

Table 2 shows how the participation in the entire ET training also grew over the semesters reaching a 93% in Fall'18. Such results corroborate some of the lessons learned and shared in Section 2.2. By providing students with an introduction and background, a syllabus for the training, and the opportunity to complete the pre-quiz (i.e. diagnostic) in class, the program becomes more relevant and appealing to the students. Also, incentivizing students by providing a final grade that evaluates their participation in the full training program is also necessary to maintain interest and motivation in the program.

Table 2. Percentage of participation in the ET

Semester	%	No. of students participating	Section size
Fall'17 first section	47%	8	17
Fall'17 second section	65%	15	23
Spring'18	70%	7	10
Fall'18	93%	14	15
Overall	68%	44	65

Authors investigated also if there was any correlation between the time students took to take the PSVT-R and their resulting scores. No correlation was found in the pre-test data set ($r = 0.1049$; $R_2 = 0.0110$) or in the post training data set ($r=0.3292$; $R_2 = 0.1084$). This result is also shown in both Figures 4 and 5. Students taking only a few seconds to answer the test in general scored low but so did some of the ones taking times near the 1800 seconds (i.e. 30 minutes) limit. Even if the average scores of the 44 participants before and after the training were almost constant, a paired t-test indicated that the times to take the pre and post diagnostic went down (from an average of 1000.41 seconds or 16.67 minutes to 678.39 seconds or 11.31 minutes) in a significant way (p-value 0.0002203). This result may indicate that the students felt more familiar with the type of questions and their level of difficulty during subsequent testing.

Analysis of the qualitative results gathered through the ET exit surveys shows that 89% of the participants completed them, 50% of them reported that the training improved awareness about the level of applicability of SVS to their careers, but only 21% expressed satisfaction from improving SVS vs. the work that was needed for this project. Thus, results from the surveys and the quantitative results reported in the previous paragraph seem to run in parallel. Students mentioned as mainly suggested enhancements: presenting 3D figures that are not all rectangular, having more in-class live demonstrations and more practice with the manipulative 3D blocks, making the software more manipulative and dedicating more time to explain the modules by providing more in-class examples. Some of these suggestions will need to be considered for future projects of this kind and agree with some of the components in intervention 3 reported by [22] as the most successful of several researched.

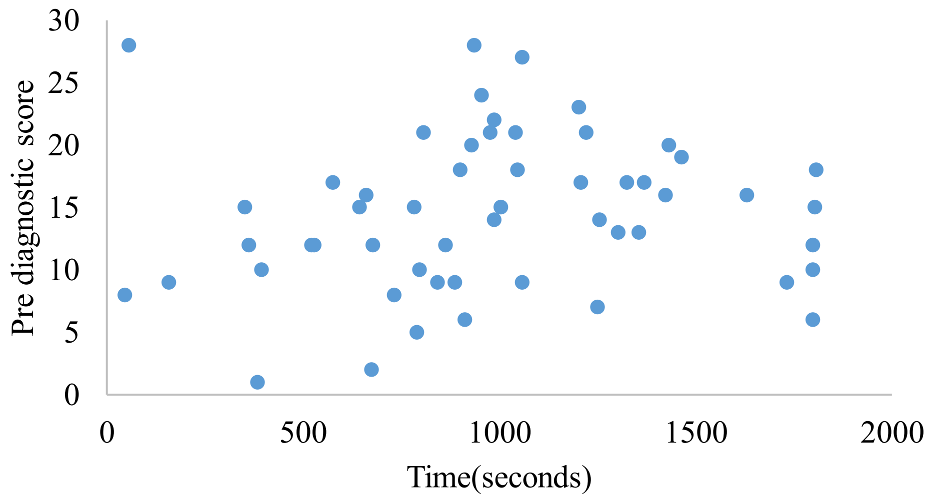


Figure 4. Times to take the pre-diagnostic vs. scores

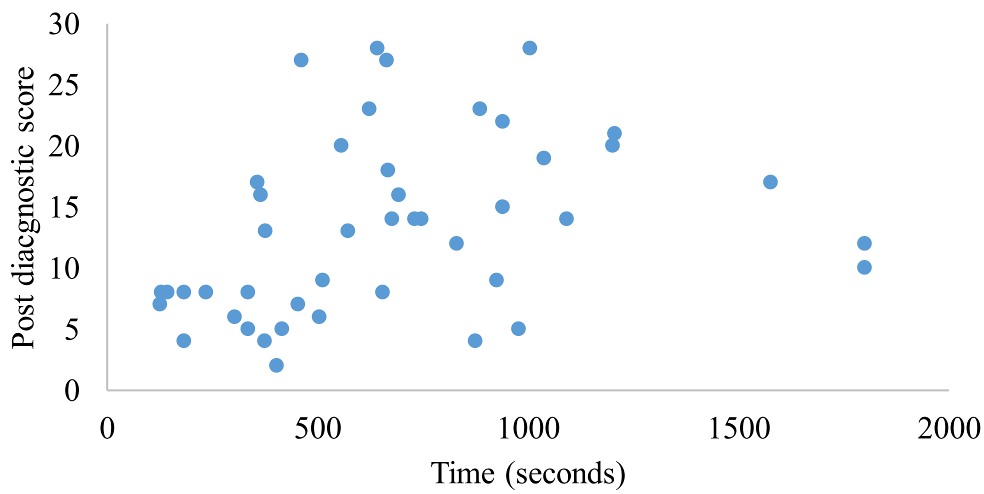


Figure 5. Times to take the post-diagnostic vs. scores

4. Conclusions

This paper presented an early SVS intervention for increasing the retention and success of STEM students. It supports the ones in [23] and [24]. Both strategies to provide the SVS training at Texas State University demonstrated to be powerful interventions to increase students' success, because they not only offered students, particularly freshman, a way to refine SVS, but also to increase motivation in STEM while creating a community among students and faculty. However, both reached a limited number of students. Analysis of the results from the voluntary FtF training showed that the training has been effective in improving SVS in the participants. Eighty five percent of the students improved. The average pre-diagnostic scores were improved by 17.65%.

It means they changed from an average of 16.85 to 22.15, which is about 5 points and brings the average scores to reach the passing level. The embedded training (ET) strategy in the US 1100 course was somewhat effective. Fifty percent of the students improved their scores, but this average improvement was nullified by the average diminishing in scores of the remaining 50% of the participants

However, the ET seems more easily apt to be institutionalized than the FtF training, but it would need to be observed over more semesters to give final conclusions about its effectiveness. Reasons for being apt for institutionalization are: (1) it doesn't require additional instructors and extra course hours for the students, and (2) the modules can be covered over a longer number of weeks permitting students with low SVS skills to have more time to understand and practice with the SVS training materials available.

It is possible to structure the embedded training in the US 1100 course. However, it would be highly desirable to embed the training in a course focused specifically on SVS. Such course could be a multi-disciplinary or a program specific introductory course to Engineering and Engineering technology programs. Taking advantage of the introductory level of the course, it would help to create students and faculty community and may let to introduce students to different applications of each engineering field through talks form speakers, plant-tours and some mini homework However, this introductory course is not currently in the Engineering curriculum but a few engineering programs are considering to take the lead on introducing those program specific introductory courses.

On the other hand, the FtF training was not obligatory and these authors believe that it contributed to the success of the students not only on improving the SVS skills, but also on making community with faculty and other students, as well as, enhancing their confidence on succeeding in their STEM careers. Some of the participants were students with not necessarily very low scores in the PSVT-R test but highly motivated to learn more about SVS and its relevance in STEM; those students deserve also high attention from STEM faculty. Besides, the FtF training took 6 instead of 10 weeks and it was effective. In some ways, it goes in line with the results in [25] where a twice a week training for half of the semester was found equivalent or superior to a 10-14 week training.

Authors of this research and students participating in the trainings were incentivized in several ways. It contributed to make this project a positive experience that has paved the way to similar STEM projects on campus such as another pilot project embedded US 1100 that focuses on enhancing performance of students co-enrolled in remedial math and college level algebra. This summer 2020, one of the authors of this paper and a faculty in the School of Engineering will be working also on another STEM project related to SVS. The project is a summer camp to high-school girls interested in STEM, in particular in engineering and engineering technology. The SVS curriculum will be included as part of the camp planned activities. Finally, the authors expect that this experimental research strengthens the literature on SVS and helps institutions wanting to start a similar project to quickly gain knowledge from the lessons learned in this project.

Acknowledgments

This material is based upon work supported by the National Science Foundation under Grant No. DUE-1431578. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Appendixes

Appendix A. Flyer used to advertise the face-to-face (FtF) training in Spring 2018

Viz Stars

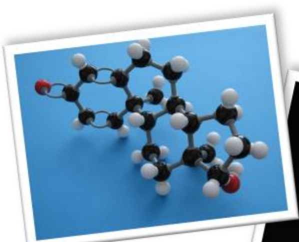
TEXAS STATE
LBJ INSTITUTE FOR
STEM EDUCATION AND RESEARCH

Promoting the Success of
College of Science & Engineering
Students

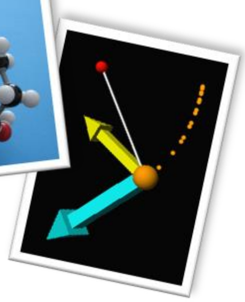
Spatial Visualization Skills

WHAT?
- SVS develop as you grow up and relate to the way you interact with objects in the world. These skills are not usually taught in school.
- Those with more developed SVS tend to get better grades, on average, in engineering, math, and science courses.
- The good news is that, as with most other skills, SVS can be improved with practice!

WHY?
- Good SVS allow you to predict how objects appear from different perspectives and in different orientations.
- SVS allow you to visualize potential solution paths when solving problems.
- SVS are essential to good design.



Courtesy of Anti-Doping Research, Inc.



HALLIBURTON

Sponsored by NSF & the Halliburton Foundation.

About Viz Stars

- Viz Stars is free! It provides you six training sessions with an instructor that will help you to improve your SVS. Spring 2018 sessions will be **Fridays, 12:00 p.m. – 2:30 p.m., March 23 – April 27, RFM 4232 (free lunch), RFM 4236 (training sessions).**
- Viz Stars includes activities, workbook, lunch, fun social community building and a chance to meet friends.
- **$25 bookstore gift cards** given to students **attending 5 sessions.**
- Viz Stars is **open to all students** in Engineering, Engineering Technology, Computer Science, Physics, Mathematics, Chemistry and Biology.

How to assess your SVS & Join Viz Stars?

Step 1. Take the diagnostic on the VIZSTARS Tracs site under the Assessments option (Available from 02/19/18 at 8am to 03/21/18 at 8pm).
- The diagnostic has 30 multiple-choice spatial reasoning problems.
- Find a quiet place with computer access and an uninterrupted 30-minute time slot. You can take the diagnostic only one time and it is timed for 30 minutes!
- Diagnostic's results are displayed to you immediately after completing it and do not affect your Texas State grades.

Step 2. Sign-up for the training through the VIZ STARS Tracs site under the Sign-up option.
- Everybody is welcome to join Viz Stars to improve their SVS!
- If your score in the diagnostic is 21 or less, we strongly recommend that you sign-up.
- Check for any conflicts between your academic schedule and Viz Stars hours before you sign-up for Viz Stars!

http://lbj-stem.education.txstate.edu/Research-Projects/NSF-Rising-Stars.html

Appendix B. Syllabus for the embedded training (ET) Fall 2018

Viz Stars Project

Background:

"What is spatial ability? Spatial ability is the capacity to understand and remember the spatial relations among objects. This ability can be viewed as a unique type of intelligence distinguishable from other forms of intelligence, such as verbal ability, reasoning ability, and memory skills. Spatial ability is not a monolithic and static trait, but made up of numerous sub-skills, which are interrelated among each other and develop throughout your life.

Why is spatial ability important? Visual-spatial skills are of great importance for success in solving many tasks in everyday life. For instance, using a map to guide you through an unfamiliar city… packing (as when you must decide if a certain box is large enough for the objects you want to put into it) and using mirror images (as when you are combing your hair while looking into a mirror [or doing chemistry!])

Spatial ability is also important for success in many fields of study. Mathematics, natural sciences, engineering, economic forecasting, meteorology and architecture all involve the use of spatial skills: For instance, an astronomer must visualize the structure of a solar system and the motions of the objects in it. An engineer visualizes the interactions of the parts of a machine. Radiologists must be able to interpret the image on a medical X-ray. Chemical sum formulas can be viewed as abstract models of molecules with most of the spatial information deleted [26].

The development of spatial visualization and thinking has been studied by many researchers and shown to improve overall learning capabilities. This program will ultimately help you be more successful in your classes!

Supplies:

- Workbook
- Computer Program
- Building blocks
- Free app [21]

Activities:

For this program we will complete a pre-diagnostic quiz, 10 modules and a post- diagnostic quiz. First item for today is to take the pre-diagnostic quiz available electronically. This takes no more than 30 min.

Also, today you are getting the workbook for the project to practice the problems and a set of cubes to help you visualize items in 3-D space (please return the cubes once you complete the modules). Each module has a descriptive video, accompanied by further explanations and examples in the computer-based program. For each module:

- First watch the video. Videos are on also on the learning management system
- Then watch the tutorial in the computer program. You can access the program from any computer on campus by typing the command that the instructor will be writing on the whiteboard**.**
- Practice modules in app.
- Then complete the examples in the workbook. Bring workbooks to class each week to monitor progress.

Schedule of Tasks:

Week 1 - 10/4/18 - Complete pre-diagnostic quiz. Complete module 1
Week 2 - 10/11/18 - Complete module 2
Week 3 - 10/18/18 - Complete module 3
Week 4 - 10/25/18 - Complete module 4
Week 5 - 11/1/18 - Complete module 5
Week 6- 11/8/18 - Complete module 6
Week 7- 11/15/18 - Complete module 7
Week 8 - 11/22/18 - **Thanksgiving**
Week 9- 11/29/18 - Complete module 8
Week 10 - 12/6/18 - Complete post-diagnostic quiz & exit survey

References

[1] S. A. Sorby, "Educational research in developing 3D spatial skills for engineering students," *International Journal of Science Education*, vol. 31, issue 3, pp. 459-480, Feb. 2009.
[2] S. A. Sorby, "A course in spatial visualization and its impact on the retention of women engineering students," *Journal of Women and Minorities in Science and Engineering*, vol. 7, issue 2, pp. 153-172, 2001.
[3] S. Metz, S. A. Sorby, J. Reap, T. Berry and L. Bottomley, "Implementing ENGAGE strategies to improve retention: Focus on spatial skills," in *American Society for Engineering Education Annual Conference & Exposition, Spatial Skills Panel, Atlanta, Georgia, USA, June 24, 2013*. Available: Engage - Engaging Students in Engineering,https://static1.squarespace.com/static/5436928ee4b03e07f798150b/t/55159382e4b090722fa990ab/1427477378872/ASEE+SVS+Panel+FINAL+2013+3.27.2015.pdf [Accessed Jan 26, 2020].
[4] D. Bairaktarova, M. Reyes, N. Nassr and D. T. Carlton, "Spatial skills development of engineering students: Identifying instructional tools to incorporate into existing curricula," in *Proceedings of the 2015 American Society for Engineering Education Annual Conference, Seattle, WA, USA, June 14-17, 2015*. USA: American Society of Engineering Education, 2015. pp. 1-10
[5] S. A. Sorby, "Spatial resources for the classroom," [Online]. Available: Higher Education Services - Visualizing Success, https://www.higheredservices.org/ [Accessed Jan 29, 2020].
[6] W. S. Swail, K. E. Redd and L. W. Perna, *Retaining Minority Students in Higher Education: A Framework for Success, ASHE-ERIC Higher Education Report, vol. 30, number 2, J-B Ashe-Eric Report Series*. New York, NY: John Wiley & Sons, 2003.
[7] L. G. Humphreys, D. Lubinski and G. Yao, "Utility of predicting group membership and the role of spatial visualization in becoming an engineer, physical scientist, or artist," *Journal of Applied Psychology*, vol. 78, issue 2, pp. 250-261, 1993.
[8] S. Sorby, B. Casey, B. Veurink and A. Dulaney, "The role of spatial training in improving spatial and calculus performance in engineering students," *Learning and Individual Differences*, vol. 26, pp. 20–29, Aug. 2013.
[9] C. L. Miller and G. R. Bertoline, "Spatial visualization research and theories: Their importance in the development of an engineering and technical design graphics curriculum model", *Engineering Design Graphics Journal*, vol. 55, no. 3, pp. 5-14, Fall 1991.
[10] Engage. (2009-2019). "Spatial visualization skills," [Online] Available: Engage, https://www.engageengineering.org . [Accessed Jan 29, 2020].
[11] A. Friess, E. L. Martin, I. E. Esparragoza and O. Lawanto, "Improvements in student spatial visualization in an introductory engineering graphics course using open-ended design projects supported by 3-D printed manipulatives," In *Proceedings of the 2016 American Society for Engineering Education Annual Conference, New Orleans, LA, USA, June 26-29, 2016*. USA: American Society of Engineering Education, 2016.
[12] D. I. Miller and D. F. Halpern, "Spatial thinking in Physics: Longitudinal impacts of 3-D spatial training", in *CogSci 2011, Boston, MA, USA, July 20-23, 2011*, L. Carlson, C. Hoelscher, T. F. Shipley, EDS. Austin, TX: CogSci, 2011. pp. 3465-3470.
[13] N. L. Veurink, A. J. Hamlin, J. Kampe, S. A. Sorby, D. Blasko, K. Holliday-Darr, J. Kremer, K. Harris, L. V. Harris, P. Connolly, M. Sadowski, C. Brus, L. Boyle, N. Study and T. Knott, "Enhancing visualization skills - improving options and success (EnViSIONS) of engineering and technology students," *Engineering Design Graphics Journal,* vol. 73, no. 2, pp. 1-17, April 2009.
[14] J. L. Segil, J. F. Sullivan, F. A. Myers, D. T. Reamon, and M. H. Forbes, "Analysis of multi-modal spatial visualization workshop intervention across gender, nationality, and other engineering student demographics," in *IEEE Frontiers in Education Conference, Erie, PA,USA, October 12-15, 2016*. USA: Institute of Electrical and Electronic Engineers, 2016.
[15] J. L. Segil, J. F. Sullivan, J. Y. Tsai, D. T. Reamon and M. H. Forbes, "Investigation of spatial visualization skills across world regions," *in IEEE Frontiers in Education Conference, Indianapolis, IN, USA, October 18-21, 2017*. USA: Institute of Electrical and Electronic Engineers, 2017.
[16] R. Guay, *Purdue Spatial Visualization Test.* Lafayette, IN: Purdue Research Foundation, 1977.
[17] G.M. Bodner and R.B. Guay, "The Purdue visualization of rotations test," *The Chemical Educator*, vol. 2, issue 4, pp 1-17, Oct. 1997.
[18] N. L. Veurink and A. J. Hamlin, "Comparison of on-line versus paper spatial testing results," in *Proceedings of the 2015 American Society for Engineering Education Annual Conference, Seattle, WA, USA, June 14-17, 2015*. USA: American Society of Engineering Education, 2015.

[19] B. M. Allan and R. G. Fryer, Jr, "The power and pitfalls of education incentives," *The Hamilton Project*, Sept. 2011. [Online] Available: https://scholar.harvard.edu/files/fryer/files/092011_incentives_fryer_allen_paper2.pdf . [Accessed Jan 20, 2020].
[20] L. K. Baranek, "The effect of rewards and motivation on student achievement," Master's Theses, Department of Education, Grand Valley State University, Allendale, MI, Summer 1996. [Online] Available: ScholarWorks@GVSU, https://scholarworks.gvsu.edu/cgi/viewcontent.cgi?article=1292&context=theses .[Accessed Jan 20, 2020].
[21] eGrove Education, Inc., "Engaging touchscreen sketching products to support STEM understanding – Spatial VisTM," Available: eGrove Education, https://egrove.education/products .[Accessed Jan 29, 2020]
[22] J. L. Segil, B. A. Myers, and D. T. Reamon, "Efficacy of various spatial visualization implementation approaches in a first-year engineering projects course," In *Proceedings of the 2015 ASEE Annual Conference & Exposition, Seattle, WA, USA, June 14-17, 2015*. USA: American Society of Engineering Education, 2015.
[23] W. P. Walton, M. Urban-Lurain, A. Idema, T. J. Hinds and D. Briedis, "Spatial visualization skills intervention for first year engineering students: Everyone's a winner!" In *Proceedings of the 2015 American Society of Engineering Education Annual Conference, Seattle, WA, USA, June 14-17, 2015*. USA: American Society of Engineering Education, 2015.
[24] K. S. Harris, L. V. Harris and M. A. Sadowski, "*Measuring spatial visualization in a high school bridge program*," in *Proceedings of the 64th Midyear Conference of the Engineering Design Graphics Division of ASEE, Erie, PA,USA, Oct. 14-16, 2009*. USA: Engineering Design Graphics Division ASEE, 2009. pp 127-131.
[25] N. Veruink and A. Hamlin, "Is condensed better? Comparison of a condensed spatial training course to a semester-long version," In *Proceedings of the 2016 American Society for Engineering Education Annual Conference, New Orleans, LA, USA, June 26-29, 2016*. USA: American Society of Engineering Education, 2016.
[26] Center for Talented Youth (CTY). "What is spatial ability?" [Online] Available: CTY – John Hopkins University, http://cty.jhu.edu/talent/docs/SpatialMore.pdf . [Accessed Jan 29, 2020]